Detection and characterization of CO_2 leakage by multi-well pulse testing and diffusivity tomography maps

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M. Shakiba
S.A. Hosseini

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Abstract

Pressure pulse testing, a type of interference well testing, has shown promising applications in subsurface carbon dioxide (CO_2) leakage detection and monitoring. In pressure pulse testing, a pressure signal generated by periods of injection and shut-in (from a pulsing well) propagates deep into the formation, and the corresponding response is recorded at the observation well(s). The shape of the signal alters as it travels between the pulsing well and the observation well. Analysis of this characteristic change is the basis for measurement of formation properties such as the total hydraulic diffusivity coefficient. If the test is repeated over time, one can detect and monitor temporal changes in the hydraulic diffusivity coefficient. In this paper, we used a modified analytical solution in the frequency domain to analyze the pressure pulse test data and to characterize the location and geometry of the CO_2 leak. Using this technique, we first transferred the periodic pressure response to the frequency domain using the Fast Fourier Transform. Then we used a modified analytical solution to calculate the diffusivity coefficient excluding the injection rate data. The derived diffusivity coefficient for each pulse test was assigned to the midpoint between the pulsing well and the observation well. Finally, a stochastic simulation approach was used to generate a large-scale diffusivity tomography map for the target formation. When this concept was applied to a network of monitoring wells, the derived diffusivity tomography map successfully located and visualized the extent of CO_2 leakage. The contour lines of the diffusivity tomography map reasonably revealed the geometry of CO_2 leakage (point-source vs. line-source leakage) and when superposed on the CO_2 saturation profile, showed very good agreement. Analysis of the results indicated that even a small amount of CO_2 leakage in the investigation zone can have a measurable effect on the calculated diffusivity coefficient. This finding can be of great importance when early leak detection is of interest. Such information can be applied to monitor plume evolution and design a remediation process. Our study shows that the pressure pulse test analysis has the capability to monitor large areas inside the formation and to detect and characterize possible CO_2 leaks with reasonable accuracy.